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WORLD-WIDE CHANGES OF TEMPERATURE

By CHARLES F. BROOKS, Ph.D.
Yale University

Why was the summer of 1916 hot and damp in the central and eastern United States? Why was that of 1915 cool and extraordinarily wet in the Middle West? Why was there so much snow in New England in the winter of 1915 to 1916? Was the weather abnormal in other parts of the world at the same time; and, if so, do past records show the simultaneous occurrence of similar extremes? Does the study of the weather of the world as a whole offer any possibilities for making seasonal forecasts? To these and other similar questions only tentative answers can now be given. Some well-established correlations between temperature departures in widely separated parts of the earth are summarized in this article; and the author has assembled weather data of recent months, which, in the absence of complete data, can be offered only as possible illustrations of these correlations.

As these correlations deal with departures from the average, a summary of the normal distribution of pressure may not be out of place here. The intense heating of the air in the equatorial regions leads to a poleward flow of air in the upper levels. On account of deflection, these winds form great whirls, the centrifugal force of which reduces the atmospheric pressure at the earth's surface in the higher latitudes and piles up the air in high pressure "belts" in the sub-tropics. This would-be orderly arrangement is greatly disturbed in winter by the coldness of the continents and the relative warmth of the oceans, which favor the formation of great high-pressure areas on the land and of low-pressure areas over the water. Thus the sub-polar low pressures are still further reduced over the ocean and more than neutralized over the continents, while the sub-tropical high pressures are increased where there is land and somewhat lowered over the water. In summer, the oceanic sub-tropical "highs" are strengthened, the sub-polar "lows" are weakened; and low-pressure areas develop over the heated continents.

It is evident from the foregoing that the changing temperature relations between land and water strongly influence atmospheric circulation, and, furthermore, that winter temperatures in places far apart may vary together in the same or in opposite directions. Such is markedly the case in the North Atlantic region, where the connections depend largely on the temperature distribution of the ocean surface waters. There, the Iceland cyclone is intensified¹ when the water in the vicinity is warmer than usual and weakened or even replaced by an anticyclone when it is colder.² When the pressure at one place is reduced, it must rise correspondingly elsewhere. Thus it is not surprising that the pressure over the Azores is higher than normal 70 to 80 per cent of the time that the pressure of the Iceland cyclone is lower than normal.³ A similar relation seems to exist between the Aleutian low-pressure area and the North Pacific sub-tropical high-pressure area, the center of which is near the Hawaiian Islands. Furthermore, pressure changes in the continental anticyclones of Eurasia, North America, and Greenland, and in the Aleutian and Iceland cyclones, seem to be of opposite sign.

Not only may warm water intensify the Iceland cyclone and, in turn, the surrounding anticyclones, but also water temperatures below normal in the vicinity of the high-pressure belt tend to raise the pressure locally and so to shift the Azores center,⁴ or perhaps to develop a separate one, as over Bermuda.⁵ Conversely, local warm water tends to lower the pressure. The water temperatures affect the pressure distribution; the pressure distribution controls the winds and, so, the weather; and, in turn, the winds through ocean currents and surface drift bring about a rearrangement of water temperatures. As western Europe and eastern North America are influenced in common by the North Atlantic air circulation, the weather on the opposite sides and in different parts of the same side should not vary independently.

Professor Hildebrandsson states⁶ that, in winter, the weather over part of the ocean lying between Iceland and Norway agrees with that of the north of Europe but is in opposition to the weather in the sub-tropical region, the Azores and the Mediterranean. The same contrast between the north and south is said to occur in North America, but inversely to the relation in Europe; so that if the winter is cold in the north of Europe, it is cold in Mexico and the United States, but mild in the south of Europe and in the north of North America.⁷ These relations, however, are often

¹ As in December, 1914, January, February, December, 1915, and January, 1916. These and other months mentioned in the footnotes are suggested as possible illustrations, water temperatures and full pressure data not being available now. See the table.

² November, 1915, March, 1916.

³ J. von Hann: *Lehrbuch der Meteorologie*, Leipzig, 1915, pp. 637 to 644, gives a good summary of European and other correlations.

⁴ To the east—March, December, 1915, January, 1916; to the west—November, 1914.

⁵ January, February, April, 1915, January, 1916.

⁶ Summary in *Nature*, Vol. 97, 1916, p. 228.

⁷ Such was more or less the case in March, 1915.

disturbed by external causes of a superior order, such as the varying heat of the sun.⁸ Correlations are usually more evident in winter, when local weather is more under the influence of the atmospheric circulation than in summer, when direct solar control usually dominates.

Let us consider these correlations in detail. In the eastern United States the type of winter weather, marine⁹ or continental,¹⁰ is determined largely by the presence or absence, respectively, of the Bermuda "high." The cause of the Bermuda "high" seems to be a cold water surface,¹¹ which may depend on the temperature and strength of the Labrador Current.¹² The cold water and ice set in motion one winter by a strong Iceland cyclone may serve to strengthen the Bermuda anticyclone and to weaken the Iceland "low" in the next winter. When the Iceland cyclone is strong, northwestern Europe is warmed by strong southwest winds, and eastern North America is cooled by the strong northwest winds of the other side. On the other hand, when the Iceland cyclone is weak, the weather on both sides tends to become normal for the latitude: which means a cold winter in northwestern Europe and a warm one in northeastern North America. Thus arise the alternating cold and warm winters in opposition on the two sides of the Atlantic, which may continue uninterrupted for a decade.¹³

Europe and eastern North America, on the contrary, may be cold at the same time, as in March, 1916. Such is the case when the Iceland "low" is displaced south and extended west, and when many anticyclones move on the northern track across the eastern United States. March, 1915, was similar to March, 1916, in the first particular but not in the second.¹⁴ The possible chains of cause and effect may be as follows: (1) intense Iceland cyclone and Azores anticyclone¹⁵—strengthened trade winds—strong Equatorial Current—warm Gulf Stream in the following winter;¹⁶ (2) strong Iceland cyclone with high northerly winds on the west side¹⁵—strong Labrador Current with much ice—cold water in the northern part of the ocean.¹⁷

Also, coincident warm weather may occur in northwestern Europe and eastern North America, as under the conditions prevailing in January, 1915 and 1916. In January, 1916, the pressure was much above normal in a belt extending at least from southern Europe across the Atlantic through

⁸ January, 1916, may have been an illustration of this condition.

⁹ January, February, April, 1915, January, 1916.

¹⁰ December, 1914, March, 1915, 1916.

¹¹ November, 1914, January, 1916, summer, 1916? Southerly winds off the ocean in midsummer bring sultry hot weather to the North Atlantic states.

¹² W. J. Humphreys: Why Some Winters Are Warm and Others Cold in the Eastern United States, *Monthly Weather Rev.*, Vol. 42, 1914, pp. 672-675, 35 charts.

¹³ Cf. Hann: *op. cit.*, pp. 639, 640, and C. Abbe, Jr.: Washington and Paris Winters, Table 2, *Monthly Weather Rev.*, Vol. 42, 1914, p. 627 (Opposition Washington-Northern Europe, 1874 to 1883).

¹⁴ See A. J. Henry: Control of March Weather by Pressure Distribution, p. 139, and Charts II, IV, and IX, *Monthly Weather Rev.*, Vol. 44, March, 1916.

¹⁵ Winter 1914-15.

¹⁶ M. W. Campbell Hepworth: The Gulf Stream, *Nature*, Vol. 93, 1914, pp. 441-443. See also footnote 33.

¹⁷ Winter 1915-16.

the southeastern United States to Alaska. The pressure of the Iceland cyclone was about normal, but the southwest winds were strong because of the intensified "high" on the south. In the Pacific, the Aleutian "low" seems to have been pushed south, for the pressures were below normal in the United States west of the Rockies and at Honolulu. These pressure conditions produced intense cold in central North America and mild weather in the East;¹⁸ while England experienced the warmest January on record.¹⁹ This strengthening of the "highs" without a lowering of pressure in the "lows" may have been in response to excessive overflow of air from the tropics.²⁰ In fact, cold weather in central North America comes with a southward displacement of the Aleutian "low," a movement not wholly unrelated to a similar one on the part of the Iceland center, as seems to be indicated in February and November, 1915, January and March, 1916. In April the connection between the two oceans seems to have been particularly patent, the important pressure reversals between the 19th and 20th being simultaneous in the Azores, the Aleutians, and Hawaii.²¹

Temperatures in the southern hemisphere seem to be no less closely correlated. Mossman²² has found that there is opposition between the Weddell and Ross Seas in pressure and wind at all seasons and opposition in temperature in winter. Furthermore, there seem to be seasonal contrasts between the Ross Sea, on the one hand, and southern South America, parts of West Australia, and New Zealand, on the other.²³ The winter of 1915 may perhaps be taken as an illustration. In Australia, the winter and greater part of the year were remarkably warm, with prevailing moist, north winds.²⁴ The Argentine winter was very cold, and the ice conditions in the Weddell Sea were severe.²⁵ South Africa was apparently colder than usual.²⁶

In addition to correlations within a hemisphere there are three types of connection between centers of action on opposite sides of the equator. One is direct, where winds flow from one to another, so that any variation in

¹⁸ Temperature departures: at Havre, Mont., $-15^{\circ}\text{C}.$; in the East, $+3^{\circ}$ to $5^{\circ}\text{C}.$ from normal January temperature (*Monthly Weather Rev.* Vol. 44, 1916, p. 48, and Chart IV). For remarks on Canadian conditions see *Nature*, Vol. 97, 1916, pp. 470-471.

¹⁹ London was warmer by $1^{\circ}\text{C}.$ than any January at least since 1858 (*Symons's Meteorol. Mag.*, Vol. 51, 1916, p. 7).

²⁰ See *Monthly Weather Rev.*, Vol. 44, 1916, p. 78; *Bull. Amer. Geogr. Soc.*, Vol. 47, 1915, p. 963. The fact that January, 1916, was abnormally wet at Sta. Lucia and, to some extent, at Caylloma in the Andes of Peru may have some significance here, as indicative, perhaps, of abnormal doldrum rains.

²¹ *Monthly Weather Rev.*, Vol. 44, 1916, p. 210. Before the 20th, pressures were below normal in eastern and southern Alaska and above normal at Honolulu and the Azores; after the 19th, pressures were above normal in Alaska (eastern and southern) and below normal at Honolulu and the Azores.

²² Review, *Geogr. Rev.*, Vol. 1, 1916, p. 323.

²³ See also R. C. Mossman: Southern Hemisphere Seasonal Correlations, *Symons's Meteorol. Mag.*, Vols. 48 and 49, 1913 and 1914.

²⁴ *Symons's Meteorol. Mag.*, Vol. 51, 1916, pp. 4-6; and *Nature*, Vol. 97, 1916, p. 471.

²⁵ *Geogr. Rev.*, Vol. 2, 1916, pp. 54-57.

²⁶ Temperatures at Cape Town and Johannesburg from *Symons's Meteorol. Mag.* were compared with those shown in Bartholomew's Physical Atlas, Part III, Pl. 10, allowance being made for the sea-level "reduction" of the latter.

DEPARTURES IN TEMPERATURE, RAINFALL, AND CONTROLLING CENTERS OF ACTION

EUROPE							NORTH AMERICA										
		London		Iceland cyclone		Azores anticyclone		Bermuda		St. Johns, N. F.			Washington, D. C.		Pierre, S. D.		
		T	R	Pr	Po	Pr	Po	Pr	T	Pr	T	R	T	R	Pr	T	R
1914	Nov....	+0.9	+	-1	0	+2	W	+3	-0.4	-3	0.1	+	+0.2	-	+1	+5.4	-
	Dec....	+1.5	+	-8	SE	+4	0	+1	+1.3	+2	-2.2	-	-1.8	+	+6	-2.8	-
	Jan....	+0.7	+	-2	SE	+4	W	+2	+0.8	+2	+1.2	-	+1.5	+	-2	+1.0	+
	Feb....	+0.4	+	-4	SE	+4	0	-1	+0.2	+5	+1.4	0	+2.4	0	+1	+3.6	+
1915	Mar....	+0.2	-	-10	far SW	-3	far NE	-8	-2.5	-22	+2.8	-	-1.9	-	+9	-4.8	-
	April...	0.0	-	-3	NE	+8	NE	-2	-0.7	+3	+2.4	-	+3.5	-	0	+4.6	+
1916	Nov....	-2.4	0	+3	E	0	N	-1	-1.2	-6	+2.2	+	+0.7	-	-3	+3.7	+
	Dec....	+2.3	+	-3	SE	+	E	-1	-1.7	-7	+2.3	0	-0.5	-	-1	+3.2	-
	Jan....	+4.0	-	-1	E	+4	E	+7	-1.1	-5	-1.1	-	+3.8	-	+4	-6.4	0
	Feb....	0.0	+	0	N	+10	N	+2	+2.6	0	-0.5	+	-0.2	0	+6	+1.3	-
	Mar....	-1.3	+		far SW					-8	-1.3	0	-2.4	-	-2	2.8	-
	April...	+0.6	+					-2	+0.1	-2	+1.4	-	+0.2	0	+3	-1.1	-
	May....	+1.8	0					+1	-0.9	-8	+0.8	+	+1.4	-	-2	-1.3	+
	June....	-2.4	0					-1	-2.0	+3	+0.9	-	-1.7	+	+1	-3.0	-
	July....	-0.8	-					+1					+0.7	0	-1	+3	+
	Aug....							+1					+0.9	-	+1	-0.6	+

Abbreviations:

T: departure of monthly mean temperature from the normal, C. degrees.

R: departure of total rainfall of the month from the normal; 0 indicates less than 10%.

Pr: departure of month's mean pressure from normal; units millibars (or kilobars), 1=0.03 inches of mercury, approximately.

Po: position of the center of lowest or highest pressure relative to the normal.

Sources: (Iceland and Azores pressures having been derived from map comparisons, or inferred, are uncertain.)

November, 1914, to April, 1915—

Charts IX, *Monthly Weather Rev.*, Vols. 43-44, Nov., 1915, to April, 1916; and tables, *ibid.*, Vols. 42-43, Nov.-Apr., 1915.

November, 1915, to January, 1916—

Monthly pressure maps of Europe in *Das Wetter*, Vols. 32 and 33, Nov., 1915, to Jan., 1916.

Maps of mean monthly pressure, Bartholomew's Physical Atlas, Part III, Pl. 12.

Monthly Weather Rev., tables, November, 1915, to January, 1916.

February to June, 1916—

Monthly Weather Rev., tables, Feb. to June, 1916.

Symons's Meteorol. Mag., Vol. 51, "Weather of the Month."

London data from *Symons's Meteorol. Mag.*; North American data from *Monthly Weather Rev.*

July and August, 1916—

Symons's Meteorol. Mag., Vol. 51, "Weather of the Month."

Washington daily weather maps of U. S. Weather Bureau.

either may be felt in the other hemisphere. On this basis, forecasts are made of the character of the southwest-monsoon rainfall in India,²⁷ and of the height of the Nile flood.²⁸ A second type of correlation is that of simultaneous expression of a common cause. Thus, when the sun's heat is more intense and produces a lower pressure in the equatorial regions, as at a time of sunspot maximum like the present, the polar pressures may rise and polar weather may then be colder.²⁹ It is possible that the following

²⁷ Summary in *Nature*, Vol. 96, 1916, p. 657; extensive review, *Quart. Journ. Roy. Meteorol. Soc.*, Vol. 42, 1916, pp. 129-132. The forecast for 1916 is summarized in *Nature*, Vol. 97, 1916, p. 490.

²⁸ *Scientific American*, Vol. 110, 1914, p. 392.

²⁹ Although Blanford (see Hann: *op. cit.*, p. 641) finds correlation of low tropical pressures and high polar pressures, with sunspot maxima, the recent investigations of Dr. G. T. Walker (review, *Bull. Amer. Geogr. Soc.*, Vol. 47, 1915, p. 963) question such a relation.

weather conditions in the middle of 1915 had such a common origin: warm damp winter in Australia, warm summer in the southern United States;³⁰ extraordinary ice conditions reported by Shackleton in the Weddell Sea, cold winter in southern South America; unusual ice in Arctic waters reported by the Danes³¹ north of Iceland and by MacMillan's expedition west of Greenland;³² pressures above normal and temperatures below normal in Canada and Alaska;³⁰ cool and very wet weather in the central United States.³⁰ It is suggestive, also, that in the central United States the three very wet Mays and Junes occurring in the last thirty-five years came in 1892, 1903, and 1915—all during sunspot maxima (the average period from one sunspot maximum to another is 11.4 years).

A third type of correlation is the delayed, indirect effect which operates through the medium of ocean currents.³³ The Gulf Stream, for instance, is supported by the Equatorial Current, the strength and temperature of which depends on the trade winds on both sides of the equator. Although this control of the weather of one period over that of a later one has been mentioned, an immediate, though speculative, example may be added here. It seems possible that the character of the summer of 1916 was connected in some degree with the weather of the summer of 1915. The warmth of the Gulf region communicated slowly by the Gulf Stream to the northeastern Atlantic may have had some part in producing the intensity of the Iceland cyclone in December, 1915. This strength of the Iceland cyclone probably set in motion southwards the accumulated ice in Greenland waters, the first effect of which was to raise the pressure about Iceland and so to give England the weather which culminated in the extraordinarily wet and snowy March (see table). In April, the reports of pack-ice off Newfoundland, with the establishment of a more or less permanent "high" east of New England, indicated, perhaps, further progress of the ice. In the northeastern United States, in April, May, and June, 1916, the resulting on-shore winds off the cool ocean brought cool wet weather; but in July, the damp ocean winds from the south were warm. To the stagnant anticyclone in the east, which at once made gentle winds and prevented rapid movement of cyclones across the United States, may be ascribed, in part at least, the July hot spell of the Middle West. It seems clear that the weather near the sources of ocean currents and the strength of the driving winds have effects thousands of miles away and months later.³⁴

³⁰ See discussions of "The Weather of the Month," "Forecast and Warnings," charts and tables in *Monthly Weather Rev.*, Vol. 43, 1915, May to August inclusive.

³¹ *Nature*, Vol. 97, 1916, p. 248.

³² *Geogr. Rev.*, Vol. 2, 1916, p. 65.

³³ "Meteorological Aspects of Oceanography" is the title of an article by Hans Pettersson in the *Monthly Weather Rev.*, Vol. 44, 1916, pp. 338-341, which deals with this subject, particularly in relation to seasonal forecasts.

³⁴ A successful prediction of the temperature over northwestern Europe last winter was made by P. H. Gallé, who based his forecast on the close positive correlation between the strength of the North Atlantic trade winds from May to October and the temperature over northwestern Europe the following December to February. See note in *Nature*, Vol. 97, 1916, p. 526.

The weather in widely separated parts of the earth is correlated because of the extensive control of the large belts and centers of atmospheric action. In the North Atlantic, for example, the strength, positions, and relations of the Iceland cyclone and of the Azores anticyclone dominate the weather of the adjacent region; and the resulting movements of surface waters of different temperatures change these centers of action. Similar relations seem to exist elsewhere. These are subsequent, however, to changes in the sun's radiation, which produce immediate, world-wide pressure alterations. Any possibilities for widespread seasonal forecasts must rest, therefore, first on an ability to forecast solar changes and, second, on a knowledge of the immediate and subsequent atmospheric effects of such variations.